51. IWK

Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

PROCEEDINGS

11-15 September 2006

FACULTY OF ELECTRICAL ENGINEERING AND INFORMATION SCIENCE

INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING - DEVICES AND SYSTEMS, MATERIALS AND TECHNOLOGIES FOR THE FUTURE

TECHNISCHE UNIVERSITÄT
ILMENAU

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Peter Scharff

Redaktion: Referat Marketing und Studentische Angelegenheiten
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Fakultät für Elektrotechnik und Informationstechnik
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Redaktionsschluss: 07. Juli 2006

Technische Realisierung (CD-Rom-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Marco Albrecht
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
ilmedia
Postfach 10 05 65
98684 Ilmenau

Verlag:
Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilrnenau

ISBN (Druckausgabe): 3-938843-15-2
ISBN (CD-Rom-Ausgabe): 3-938843-16-0

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=12391

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Temperature influence on capacitive sensor structures

INTRODUCTION

The non-contacting working principle of capacitive sensors is applicable for detection of dielectric and metallic targets in harsh industrial environments. Their advantages are the low power consumption, simple geometry and simple construction. The capacitance characteristic is insensitive to colour and surface of targets independent of visibility, but is influenced of various other factors like contamination, deposits, humidity, dirt and also changes of temperature over a wide range. For example its use should be stable independent of geographical area, season or any climate changes. Typical applications is the object detection in harsh industrial environments with capactive changes better than $\Delta C = 10fF$, especially with flexible dielectric layers. Two proximity characteristics with switching threshold are shown in Fig. 1. The influence of temperature dependent impedance changes makes detection difficult on different temperatures, so its compensation is one of the central requirement for accurate and relieable capacitive sensors.

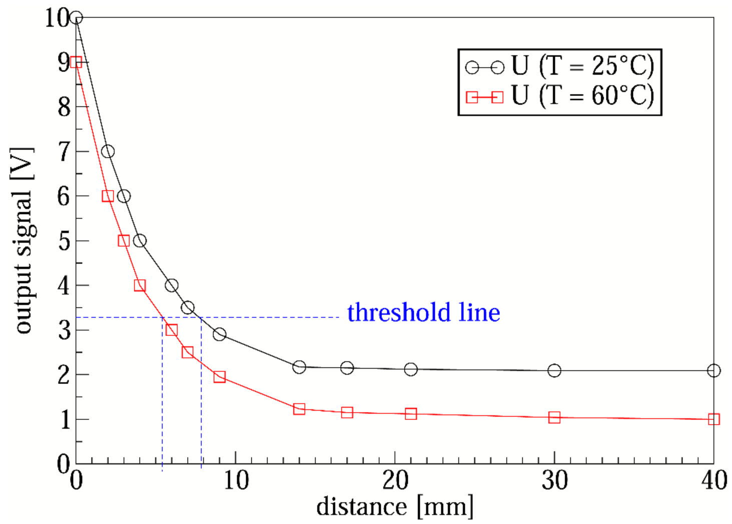


Fig. 1. Typical proximity characteristic with temperature dependency.

To eleminate the temperature dependency it is possible to use temperature independent materials with low and stable permitivitty between electrodes. Many capacitive sensors (i.e. proximity sensors) will manufactured of dielectric materials like thermoplastics, polyamide and polymers. These materials are applicable, because of their chemical and thermal resistance but especially of the low permittivity. Several studies show, that their permittivity is beside frequency dependence also depend to temperature ([2], [5]). In addition to this, the thermal expansion causes electrode- and material displacements and consequently mutual capacitance changes. Concerning of simultaneous changes it is difficult to separate these effects. Thus the sensor cannot differentiate between target proximity or other environmental effects, so that a accurate detection is

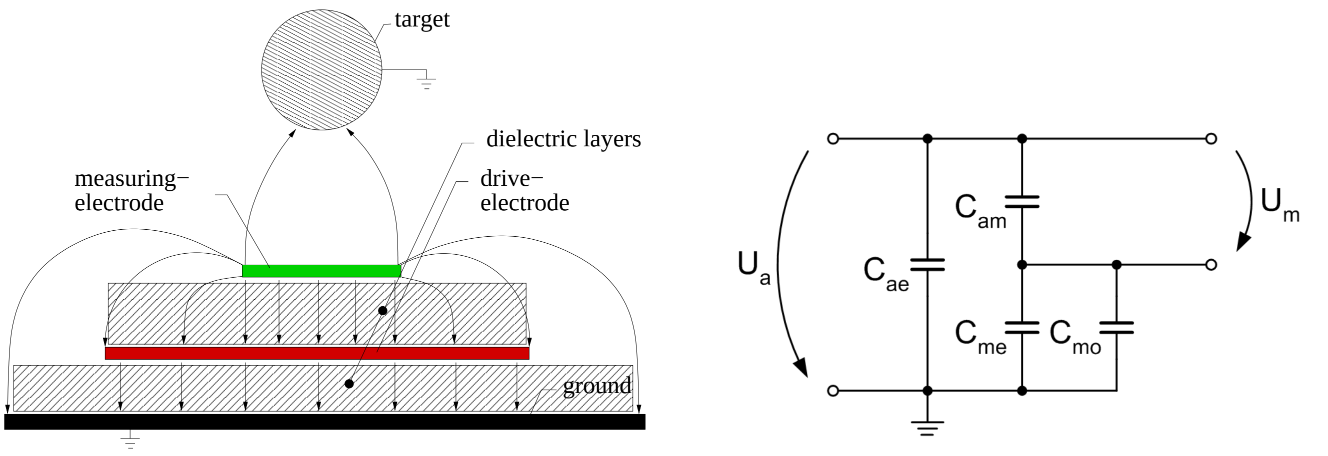
not possible in a wide temperature range. The combination of using low permitivitty materials and a suitable compensation principle can minimize or even eleminate the problems of temperature drift.
Our aim is to develop a high sensitive and flexible geometric sensor system including operation check and autocalibration, which is insensible to temperature changes in a range $T = -30$°C-220°C.

SENSING STRUCTURE

The analog measuring principle shown in Fig. 2 is based on the patented three electrode system [3], which does not operate with an oscillation principle, but rather with an additional drive electrode which is suitable for field formation [1]. A similar capacitive reflectorprinciple is used by Vranish [4] for robot collision-avoidance. So the three-electrode principle is able to detect objects at distances up to some decimetres, further it is simple to change electrode adjustments and scale the geometry of the sensor structure with simple circuitry adaptation. The system has good electromagnetic compatibility (EMC) and intrinsic burst-stability, because of using a trapezoid excitation signal V_a with fundamental frequency at $f_0 = 20kHz$. The output signal V_m is primarily influenced of the capacitances C_{me}, C_{mo} and C_{am}

$$U_m = \frac{C_{me} + C_{mo}}{C_{me} + C_{mo} + C_{am}} \cdot U_a \, . \tag{1}$$

Hardly important is C_{ae}, which is only a capacitive load for the generator. Serious temperature influence have the capacitances C_{me} and C_{am} which are due to dielectric layers between electrodes. The intrinsic measuring capacity C_{me} should be low, to get a high sensibility as a result of a large influence of C_{mo}. This can be achieved with a large drive electrode, which brings a shield effect to mass. The second important capacity C_{am} can be minimized with a relative large distance between drive electrode and measuring electrode. However, all dielectrical materials should have low and stable permittivity over temperature.



(a) Three-electrode sensor principle.

(b) Equivalent circuit (C_{me} between measuring electrode and mass, C_{mo} between measuring electrode and target, C_{am} between drive- and measuring electrode).

Fig. 2. Capacitive three-electrode sensor principle and equivalent circuit [5].

EXPERIMENTAL CONFIGURATION

For analysis of temperature influence, a simple sensor structure in Fig. 3 with Teflon layers between measuring- and drive electrode is modelled and measured in a complete electrical shielded climate chamber.

The temperature characteristic shows a continuous decreasing output signal V_m. Numerical field computations are based on a finite-element package MAXWELL and show similar tendencies by changing permittivity over the range $\varepsilon_r = 2.0 - 2.8$. Static measurements [[5], p.37] could verify these values for relative permittivity with $\varepsilon_r = 2.175$ at $T = 20°\text{C}$ and $\varepsilon_r = 2.791$ at $T = 88°\text{C}$. Numerical computations are showing only tendencial conclusions, because it is difficult to make well-defined temperature to permittivity correlations of the dielectric materials. The reasons are basically incomplete manufacturer informations about permittivity characteristics over a wide temperature range.

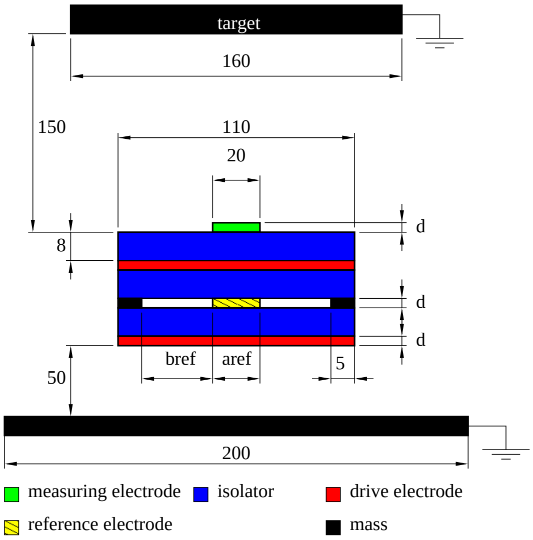


Fig. 3. Proposed prototype sensor structure [5].

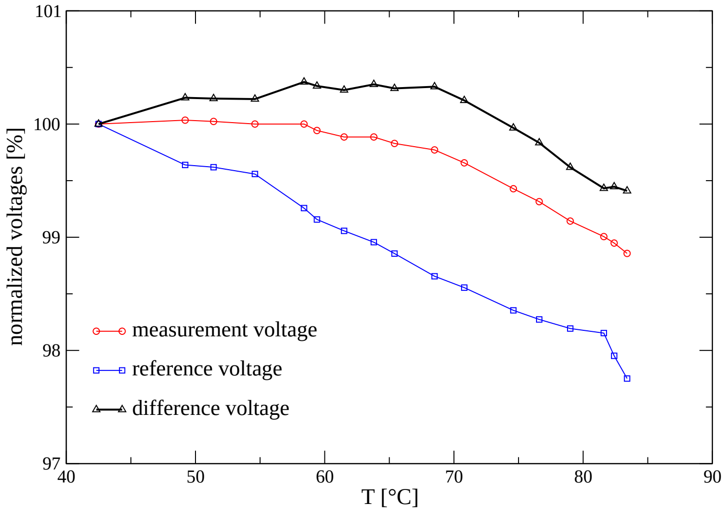


Fig. 4. Temperature characteristics of a proposed prototype sensor.

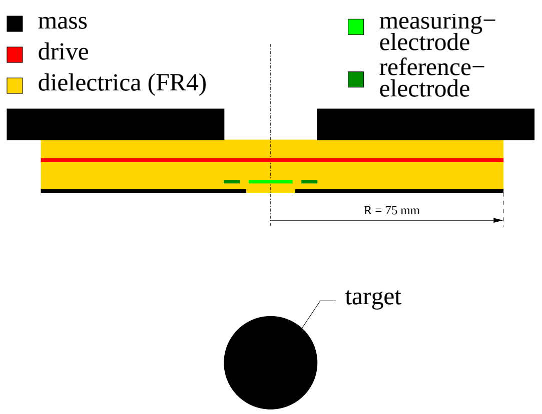
Experimental Results

To reduce or eliminate the decreasing temperature characteristic, the differential sensor structure with additional reference element only influenced by temperature changes, is used. This prototype with sandwich structure is measured for temperatures from $T = 20°\text{C}$ up to $T = 90°\text{C}$. For reduction of the thermal expansion effect, the structure is fixed in a screw clamp. Fig. 4 shows the measured outputs (normalised to $T = 40$°C) of measuring- and reference electrode and its differential signal V_d.

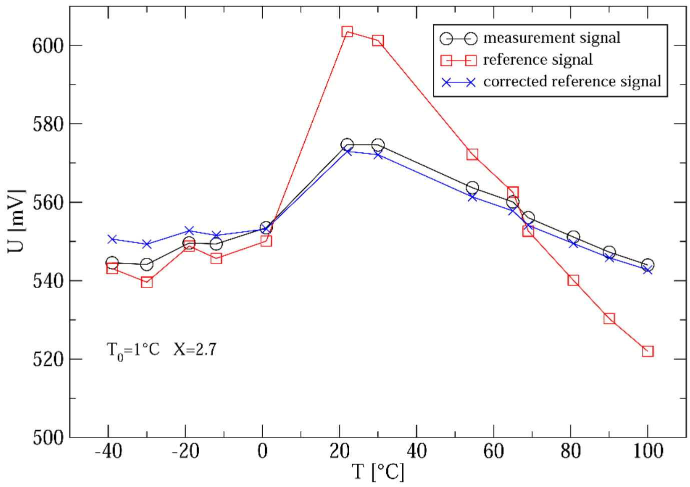
The differences of measuring- and reference graph are not practicable for object-detection with analog bridge compensation. But both have same tendencies and give base for optimisation of our differential structure. With a redesigned planar structure including epoxy resin isolator (FR4) (Fig. 5(a)) and a digital calibrating and measuring controller algorithm we developed a compensation function over a range $T = -40$°C-100°C

$$U^*_{ref}(T) = \frac{U_{ref}(T) - U_{ref}(T_0)}{X} + U_{ref}(T_0). \tag{2}$$

Equation (2) corrects the reference signal around the working temperature T_0 with a geometric dependent scale factor X. So the measurement signal and corrected reference signal should have identical temperature characteristics which are the requirements for temperature independent sensor behavior. Our sensor shows similar characteristics in Fig. 5(b) with a deviation about 1.0%. The difference voltage is calculated with the equation $\Delta V(T) = V_m - V^*_{ref}(T)$ and gives the information about the target distance.



(a) Differential structure.



(b) Temperature characteristic of the output signal and corrected reference signal (target distance 50mm, $\hat{U} = 5V$).

Fig. 5. Differential structure and temperature characteristics.

For correction of temperature characteristic the reference electrode must be independent on target distance. Numerical field computations are showing a stable output signal over target distance down to $30mm$. At lower distances the reference output rises up to a maximum, which is 0.8% higher than its basis signal. Experimental results are showing different output levels. The simulated signal differences of measuring electrode are about -2.5% and about 6.5% of reference electrode. Perhaps our equivalent circuit is not complete yet or the evaluated permitivitty of isolator is different to reality. Except for the output level differences the qualitative outputs behavior are similar. Due to the geometrical position of the reference electrode, the reference output signal is almost independent on target distance with deviation under $1‰$ (Fig. 6).

Conclusion

A temperature-compensated, fixed capacitive proximity sensor with a measuring- and reference electrode is designed, developed and tested. The system operates with a differential principle [3], which does work with an additional drive electrode for field formation and high sensitivity. The reference output is used to

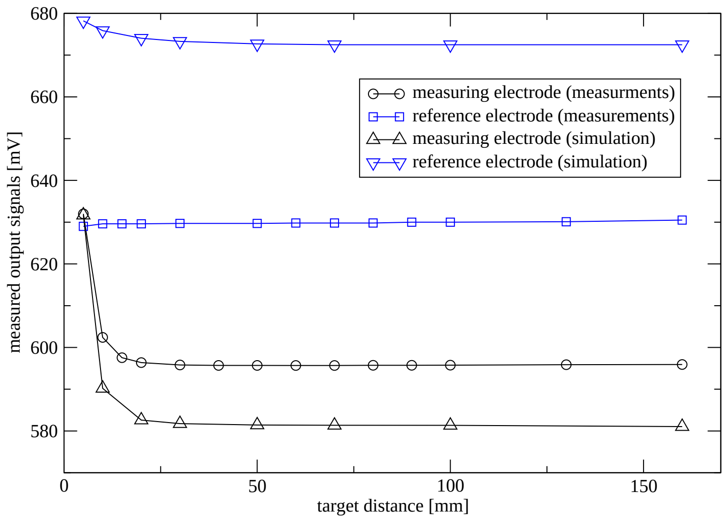


Fig. 6. Numerical solution results and experimental results of measurement- and reference signal versus target distance (T=25°C).

compensate temperature drifts of the measurement output signal, which is realised with a correction function. For object detection the outputs must have identical tendency characteristics. To adjust the tendency of reference output and the geometrical position and size of the reference sensor. So it is possible to detect objects accurate to distances of any decimetres over a range about $T = -40$°C-100°C. Current results are a good base for developing further applicable structures with temperature stability in a range $T = -40$°C-180°C

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